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ABSTRACT

Two instructors at Bunker Hill Community College in Massachusetts have developed a unit of study designed to teach biology as a process, improve students' critical thinking and reasoning skills, and provide students with the opportunity to express these skills in writing. The instructional strategies employed in the unit are superimposed on a traditional and audio-tutorial biology course. Components of the unit, which are introduced throughout the term, include the following: (1) students are presented with two papers, a natural science study and a study pertaining to the field of science education, to help them begin to differentiate between the natural sciences and disciplines which used the procedures of science, and to acquaint the students with both the structure of an academic paper and the concept of a controlled experiment; (2) students meet in small learning groups to analyze the papers, uncover errors which could lead to an incorrect conclusion, and determine how these factors are controlled; and (3) students are given another set of scientific and nonscientific papers to look for errors in logic and experimental design and then asked to redesign the experiment. A preliminary study reveals some success with this inductive process. 18 references are included. (AJL)

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TEACHING GENERALIZED PROBLEM SOLVING AND SCIENCE AS A PROCESS

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by:

Charles C. Self

Paper presented at the National Conference on Student-Centered Learning, Bellingham, Washington
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TEACHING GENERALIZED PROBLEM SOLVING AND SCIENCE AS A PROCESS

by
CHARLES C. SELF

I address two concerns which may,on the surface, seem unrelated: the teaching of science as a process and the development of generalized problem solving skills. However, if one gives the matter some thought he/she will see that the problem solving skills of the scientist are not unique to those disciplines classified under the natural sciences. The behavioral sciences utilize the controlled experiment, and the formal reasoning used in the natural sciences is found in most academic areas in colleges and universities.. As the intellectual pursuits of academia encompass, in one way or another, the full scope of what is known or unknown, we must assume that these procedures and forms of thought will be of value in addressing the day to day problems in an individual's life. The only question is: Can the formalized reasoning skills taught in a science course be generalized to other academic areas or life's general problems?

This question is pertinent in light of beliefs common to practitioners in the field of cognitive psychology. The following quote from Nisbett et al. summarizes two important positions:

> Twentieth-century psychologists have been pessimistic about teaching reasoning, prevailing opinion suggesting that people may possess only domain-specific rules, rather than abstract rules; this would mean that training a rule in one domain would not produce generalization to other domains. Alternatively, it was thought that people might possess abstract rules (such as logical ones) but that these are induced developmentally through self-discovery and cannot be trained.....(1987)

However, recent research has suggested that the two views noted above may not be valid (Nisbett et al., 1987). These authors report that probabilistic reasoning may be taught through examples training, and training in the logic of the conditional through a combination of abstract rules and examples training. Our own studies (Self et al., 1988) suggest this may indeed be the case.

The procedures which I will soon describe were derived a full year before the Nisbett paper was published, and resulted from personal experience and reasoning based on the cognitive style of our students.

My wife (Dr. Mary Anne Self) and I have developed a unit of study which is designed to teach biology as a process, to improve the student's skill in critical thinking and reasoning, and to provide students with the opportunity to express these newly acquired skills in writing. Our use of the term "unit" should not be construed as a discrete educational experience with a specific time frame. The instructional strategies employed in this unit are superimposed on a traditional and audio-tutorial biology course. Components of this segment of the course are introduced throughout the semester. Individual

instructors determine the amount of time to be devoted to this material. In general the unit utilizes three of the fifteen laboratory periods available to us during the semester.

We have taken an inductive approach in the development of our units. A number of studies at Bunker Hill Community College have indicated that 65 to 70 percent of our students are concrete conceptualizers (Self, 1983, Self, 1985, Self, 1988). Such individuals are overly bound to concrete reality, and have not yet developed genuine symbolic and abstract models of thought (Gleitman, 1981). The concrete conceptualizer has not acquired generalized problem skills, and often finds it very difficult to apply generalizations to specific situations or occurrences (Nisbett et al., 1987). Therefore, we begin with examples and from these attempt to develop generalizations which the students will later be expected to recognize, and then to apply in a research project of their own.

The unit begins with the presentation of two papers to the students. One paper is a natural science study and the second paper pertains to the field of science education. This component of the unit is designed to help the student begin to differentiate between the natural sciences and those disciplines which utilize the procedures of science, but which are not classified as a natural science. They also are use to acquaint the student with the structure of an academic paper, and the concept of a controlled experiment. We realize that a controlled experiment is not necessarily a part of the design of every observation a scientist may make (Brandwein et al., 1958). However, the controlled experiment which requires the ability to control variables is regarded as an important component of formal logic (Tobin & Capie, 1981), and its importance is stressed by authorities in both the sciences and the social sciences (Brandwein et al., Tuckman, 1972).

The scientific paper is one by Charles and Francis Darwin on the growth of canary grass seedlings (Gabriel and Fogel, 1964). We find this to be an excellent example of a scientific study, and with the exception of explaining what a cotyledon is the students have little difficulty in understanding it. The science education paper is an in-house study (Self et al., 1984) which, like the Darwins' study, contains a hypothesis and an experiment with a control group and an experimental group. In this first exercise students develop generalizations regarding the structure of a scientific paper as well as the concept of adequate controls in scientific experiments. At the same time students are exposed to deductive and inductive reasoning.

The students read the science education paper first because its structure is well differentiated by titles as to method, results, discussion, and conclusion. Students are asked to look for the elements which are contained in each of the sections of the study. They are also asked to identify the question being asked, the hypothesis, the experimental and control groups. After reading the paper the students are then given a brief lecture by the instructor using the specific example of the paper to point out generalizations regarding the materials contained in an introduction, method, and the other portions of the paper.

During the second half of the exercise, students meet together in small learning groups or "Think Tanks." We realize that grouping students is not a popular method of teaching in the sciences, but perhaps it should be. Research

has demonstrated that individuals with differing cognitive styles prefer different methods of instruction (Cross, 1976). From an ecological point of view, cognitive styles may be regarded as the perceptual and information-processing aspect of the larger system of behavior evolved by the individual as his/her strategy of responding to environmental demands (Self, 1985).

One behavioral strategy developed by field-dependent individuals is to avoid majoring in college in biology or other sciences (Witkin et al.,1977). The observations that field-dependents do not major in science as often as field-independents, and that women in Western societies and blacks are more likely to be field-dependent than white males (Witkin et al., 1977, Cross, 1976) has led some to consider manipulating instructional activities as a means of increasing minority participation in science (Kahle, 1982).

Research at BHCC has shown that the majority of students at Bunker Hill are field-dependent (Self,1985) In a sample of 200 students 161 individuals were found to be field-dependent. Studies at BHCC have supported the hypothesis that field-dependent students function best in a group situation (Self, 1984). This study found that the use of highly structured groups with a definite purpose resulted in reduced attrition and improved grades. Based on these experiences we have introduced grouping in all sections of Biology 101.

The "Think Tank", which meets throughout the semester, keeps a log which indicates the questions addressed, the contributions made by each member, and the conclusion which the group reached. This document provides individual and group accountability to the instructor. It also provides the instructor with the wonderful opportunity to demonstrate to the students how their own thought processes work.

The "Think Tanks" are asked to analyze the two papers to determine where errors might have occurred which could lead to an incorrect conclusion, and how these factors are controlled. During this discussion it is discovered that the Darwins were dealing with materials with a limited number of variables which could be controlled physically. On the other hand, in the science education paper the subject was so complex that the investigators were forced to deal with the variables statistically. We do not attempt to teach statistics, but do note that such procedures exist and are acceptable in science. This is a stepping stone for a very simplified discussion of levels of certainty.

The next step also involves two papers, which were prepared specifically as lab exercises. As before, one study, an experiment in parapsychology, is not scientific, that is, it can not be repeated and produce the same results every time. The second study deals with an experiment in photosynthesis and is reproducible. With both of these papers the following instructions are given:

> Read the attached paper. As you read, look for errors in logic and experimental design. Be sure that the results support the conclusion. Note any bias on the part of the author. If there is any doubt as to the accuracy of any statement check the references.
> Meet with your Think Tank and re-design the experiment. Go to the library to obtain information which will document any

statement you make that is based on authorities. (Self, 1986)

If one reads these papers quickly they will appear quite reasonable. However, they are liberally sprinkled with the errors indicated above. Some of these errors are rather subtle. For example, in the parapsychology experiment the question is "Do women have more highly developed intuition than men?" If the hypothesis is stated positively; "Women have more highly developed intuition than men.", the experiment given cannot disprove it. However, it will disprove the hypothesis that women do not have more highly developed intuition than men. Another interesting aspect of this paper is that the manner in which the data are organized will determine whether it supports or refutes the hypothesis. This gives us the opportunity to emphasize the importance of the proper organization of data in research.

Having analyzed each paper carefully, the students then redesign the parapsychology experiment and the photosynthesis experiment utilizing the materials given in the original papers. The students conduct the experiments and collect and analyze their data. They are required to repeat their experiments. The photosynthesis experiment will always produce the same results. The parapsychology experiment has never produced the same results twice. This gives the instructor the specific information needed to develop the generalization that in order for an experiment to be scientific, it must be able to be duplicated.

Up to this point in the course our students have had a frame of reference from which to develop their experiments. They have had the opportunity to identify the types of errors often inherent in experimental design. They have also had a model to imitate in the writing of their own papers. In the third part of this unit the students are turned loose. They are given a question, and a list of materials available to answer that question. They have to develop their own hypothesis, design and conduct an experiment, and report their findings in a scientifically acceptable format.

In the first two parts of this unit specific examples were given in order to draw generalizations. In the third section the process was reversed. Students are expected to draw on their generalizations to solve a specific problem.

We have been quite pleased with the preliminary results from implementing the techniques described in this paper. Initial evaluation procedures have indicated an enhanced understanding of science as a process in BHCC students, and an improvement in formal reasoning skills. While I do not believe that this is the proper place or format for the presentation of technical materials, I do feel that a brief overview of our evaluation procedures and results might be of interest.

In order to evaluate these procedures the four sections of Biology 101 were divided into two experimental groups which were subjected to the treatment described in this paper, and two control groups which were subjected to the standard deductive type labs which had been in use at BHCC for a number of years. The experiment was conducted over a period of three semesters.

Two instruments were used to evaluate the" science as a process" units. One of these was a science literacy test developed by the staff at BHCC. This

is a free response test which requires specific answers. For example, students are given the results of several papers from Science and asked "What is the probable question these researchers are asking?" They were then asked to write a hypothesis which was appropriate to the question. Using only the data reported in these papers, the students are instructed to state whether the results supported or refuted the hypothesis. In another section of the test the students were given classic papers in biology and asked to identify the hypothesis, the control and experimental groups, and to determine whether the data supported or refuted the hypothesis. The students were also given parts of a scientific paper and asked to identify the section (introduction, method, etc.) from which it was taken.

The t-test for a difference between two independent means was used to compare the performance of the control and experimental groups. In every case the experimental group performed significantly (Alpha=.001) better on the science literacy test than did the control group.

The second test used to evaluate the units was The Test of Logical Thinking (Tobin & Capie, 1981). The Test of Logical Thinking (TOLT) was developed by Tobin and Capie as an instrument to assess formal reasoning ability in individuals that range in age from adolescents to college age adults. It is an objective paper and pencil test designed to replace the clinical interviews required by the test of formal reasoning described by Inhelder and Piaget (Tobin & Capie, 1980). The instrument was validated on the Inhelder and Piaget test, and a correlation of .80 exists between performance on interviews and TOLT.

The TOLT was designed to measure long term changes, and is not intended to measure short term change (Capie, 1988). However, as there is a paucity of good reasoning skills test it was decided that while students may not make great jumps from concrete to abstract conceptualizers, if they were developing new problem solving skills it could be expected that they would show some improvement on some of the subtests.

As the TOLT came to our attention only recently, the data obtained from this test is limited to 28 subjects in the experimental classes and 26 students in the control group. Although the data is very tentative at this point it is also very striking.

There are two forms of the TOLT (form A and form B). Form A was given to the subjects the second day of class, and form B was given a week after the experimental units were completed. A perfect score on both forms of the TOLT is 10. The mean score for the experimental group was 3.25 on form A, and the mean score for the control was 2.89. The t-test suggested that the difference between these two scores was probably due to chance (Alpha).20). On the second test the mean for the experimental group was 5.57, and the mean for the control was 3.07. The difference between these two means was found to be significant at the .005 level. The t-test for related measures indicated that the improvement in TOLT scores by students in the experimental class was significant at the .001 level. This test also failed to demonstrate any significant difference between scores on form A and form B for the control group.

In addition to these objective measures we have observed many subjective

occurrences which may only be processed at an emotional level. These "gut feelings" only enhance our belief that what we have done has benefited our students. While we do not suggest that our procedures will be successful in all colleges or with every student we do believe that we have demonstrated that there is much merit in addressing the cognitive styles of our students.

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